Warning Signals and Driver Re-engagement for Individuals with Autism Spectrum Disorder

Senior Research Thesis

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by

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Abstract

Autonomous systems are in their infancy in terms of total vehicle comprehension of surrounding events, and for some years into the future, these technologies will require the individual to regain control of the vehicle during unpredictable events. Previous studies have not investigated the relationship between individuals with Autism Spectrum Disorder (ASD) and re-engagement with driving. Given the extensive literature on sensory defensiveness in individuals with ASD in non-driving situations, the method used to alert drivers to re-engage may cause particular difficulties for this population. In the present study, licensed adult drivers with and without ASD completed an autonomous driving scenario in a simulator at the Ohio State University Driving Simulation Laboratory. When an unpredictable situation occurred, the vehicle presented a warning signal from one of three sensory modalities to alert participants to re-engage with driving. These signals included visual flashing lights, haptic seat vibrations, or auditory tones, that prompted the driver to take control of driving. Re-engagement time was measured by how long it took the participant to come in contact with the steering wheel or brake pedal. Data collection is still underway, but results to date showed that there was a significant main effect of warning, with auditory and haptic warning signals producing the shortest reaction times. Data analysis using ANOVA did not show a significant main effect of ASD, despite the trend towards longer reaction times in that participant group. When completed, the results of this study may give us new insights in relation to the experience of individuals with ASD, warning signals and re-engagement time with autonomous vehicles. This will provide automakers with guidance in vehicle

design to accommodate both typically-developing and special populations to make the vehicle experience inclusive for all users.

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Table of Contents

Chapter 1: Introduction

Vehicles are becoming more autonomous and while these features may be beneficial to normally developing individuals, there may be populations that require adaptability in autonomous features. In the long term, autonomous vehicles will not need significant oversight or input from a driver, but in the short term, this up-and-coming technology may require the driver to intervene and, depending on the situation, this may require fast reengagement. To elicit a quick reengagement with the vehicle, an alert must be presented to inform the driver that he or she needs to intervene. Independent transportation can enhance quality of life of those with ASD by enhancing employment and social opportunities.

Individuals on the autism spectrum may react differently or adversely to sensory modalities that alert them to reengage in the vehicle. Literature suggests that individuals with autism spectrum disorder (ASD) have sensory defensiveness which may negatively affect their reaction to the warning stimuli. Sensory defensiveness can be defined as a negative reaction to specific sensory inputs such as tactile, vestibular, auditory, visual, gustatory, olfactory or proprioceptive, which would typically not be interpreted at aversive (Pfeiffer and Kinnealey, 2003).

It is known that sensory defensiveness increases with increasing stimulus intensity, and therefore individuals on the spectrum will typically dislike more intense stimuli. Autonomous vehicles may need an intense stimulus to get the driver to pay attention, however it is possible that this may elicit tactile defensiveness in individuals with ASD. Tactile defensiveness is characterized by behavioral hyperresponsiveness and negative emotional responses to touch, is a common sign of abnormal sensory processing in ASD and other developmental disabilities. In a study by Cascio, Lorenzi, and Baranek (2016), it was found that children with ASD and developmental disabilities showed significantly more defensiveness reactions and lower pleasantness ratings than the typically developing group. This is important to consider when designing vehicles for special populations that may react adversely to certain stimuli. A warning stimulus that produces a quick re-engagement time is important, but it must not cause an impairment in executive functioning.

Sensory defensiveness can also be related to anxiety, which is a state of uneasiness which can either promote or interfere with functioning. In a study by Pfeiffer and Kinnealey (2003), it was found that there was a significant relationship between sensory defensiveness and anxiety. This was because individuals with sensory defensiveness had low thresholds for sensory stimuli, which led to heightened responses and, therefore, increased anxiety. It is difficult to determine whether an increase in anxiety in individuals with ASD could cause negative or positive outcomes in driver re-engagement. Too high a level of anxiety would likely be detrimental, but a low to moderate level of anxiety could enhance attention and vigilance.

Very few studies have been performed in relation to autism and driving. A study by Chee, Lee, Patomella, and Falkmer (2017) investigated the relationship between driving behavior and ASD. Based on the results, drivers with ASD underperformed in vehicle maneuvering, specifically at left-turns, right-turns and pedestrian crossings. Drivers with ASD, however, outperformed the typically developing group in aspects related to rule-following such as using a turn-signal and checking for cross-traffic when approaching intersections. Based on this finding, it is difficult to say what the driving experience would be for an individual with ASD in an autonomous vehicle.

Daly, Nicholls, Patrick, Brinckman, and Schultheis (2014), investigated driving history and the driving behaviors of adults diagnosed with ASD. Seventy-eight licensed drivers with ASD completed a driver behavior questionnaire in which they self-assessed their driving performance. Drivers with ASD provided significantly lower ratings of their ability to drive, and reported higher numbers of traffic accidents and citations compared to non-ASD drivers. These findings suggest that drivers with ASD may experience more difficulties and engage in more problematic driving behaviors than those without ASD (Daly et al., 2014). However, because this was a questionnaire, it is possible that the self-reports were not reflective of the true driving behaviors of those with ASD.

The Present Study

Some additional limitations of previous studies involve the fact that these studies used computer simulations rather than actual driving or were post-hoc self-report studies. Desktop computer simulations are unrealistic and may produce behaviors that are different from real-world situations. Very few studies have looked at the driving experience with realistic conditions in individuals with ASD, and none to date have studied the response of individuals with ASD to autonomous vehicle technologies.

Until autonomous vehicles are perfected, a process that will likely extend over at least a decade, it is expected that autonomous vehicles will need input from the driver when there are situations that are unpredictable. Weather conditions such as snow, rain or hail may impact how the vehicle's sensors behave. However, it is unclear if the reaction time of an individual to engage depends on whether that individual has ASD or not. It is important to present a warning signal that will elicit the quickest reengagement time, especially when the situation is dire. The present study addresses this question by measuring participants' reaction time to various warning signals (visual, auditory, and haptic) when prompted to re-engage with the vehicle in a pre-designed scenario. Individuals with and without ASD were tested.

In the present study, these questions of ASD status and the most appropriate warning signal were addressed. Individuals with and without ASD were recruited to drive a driving scenario in a realistic, motion-base driving simulator. Reaction time to reengage in the vehicle was measured. In the autonomous driving future, it is assumed that the occupant will focus his or her attention on other activities, such as using a phone, playing a game, watching a movie or reading a book while the car drives. In this simulation, the participant played "Candy Crush" on an iPad during the autonomous drive. At random intervals, an "unpredictable" situation occurred in the simulation. Once the unpredictable situation occurred, the vehicle prompted the driver to take over via a warning. The participants were then repeatedly prompted to reengage in the vehicle while being exposed to one of the 3 warning signal stimuli, repeated in a random order. The stimuli included visual lights, auditory stimuli or haptic vibrations. Re-engagement time was measured by how long it took the participant to come in contact with the steering wheel or brake pedal.

Mixed results in the previous literature notwithstanding, the hypothesis for the present study was that there would be a main effect of autism status, with individuals in the ASD group exhibiting longer re-engagement times for all stimuli. It was also hypothesized there would be a main effect of warning signal, with auditory stimuli producing a faster reengagement time than the other modalities. Previous results in the literature suggest that sensory transmission of visual stimuli is slower than that of auditory stimuli. The transduction process and the succeeding processing from the outer segments of the photoreceptors to the first action potential in the visual system can require tens of milliseconds. In contrast, the transduction processes of the auditory system are much faster, with the spiral ganglion cells firing action potentials within milliseconds in the cochlea (Recanzone, 2009). More importantly, the participants were very unlikely to be looking in the location from which the visual stimulus was presented, which would make perception time longer.

Sensory defensiveness increases with higher stimulus intensity (Pfeiffer and Kinealey, 2003). Individuals on the spectrum tend to dislike more intense stimuli. Pfeiffer and Kinealey found that there is a significant relationship between sensory defensiveness and anxiety. This is because individuals with sensory defensiveness have low thresholds for sensory stimuli, which may lead to heightened responses and therefore increased anxiety (Pfeiffer & Kinnealey, 2003). Conversely, individuals without autism may have faster reaction times during more intense stimuli because this may elicit a startle reflex. It was hypothesized that individuals with ASD might experience higher levels of anxiety when warning stimuli were presented, leading to longer reaction times. Haptic stimuli were hypothesized to produce a particularly large differential effect, with participants with autism having longer reaction times than participants without ASD. This is because of tactile defensiveness in the ASD population, which is characterized by behavioral hyperresponsiveness and negative emotional responses to touch and is a common sign of irregular sensory processing in individuals with ASD (Cascio, Lorenzi & Baranek 2016).

Chapter 2: Method

Participants

The present study received approval from the Ohio State University Institutional Review Board (IRB Protocol 2013B0050, PI Janet Weisenberger). Twenty-two participants (11 men, 11 women), with valid driver's or temporary licenses were tested. Four participants (2 men, 2 women) had Autism Spectrum Disorder (ASD) and eighteen participants (9 men, 9 women) did not have ASD. ASD status was self-identified by the participants. Participants were recruited via email and social media.

Simulator Equipment and Scenario

The present study used a Realtime Technologies Inc. (RTI) simulator with a 2010 Honda Accord cab mounted on a 6 degrees of freedom motion-based platform. Participants drove a 30-minute simulation pre-programmed to disable the car's autonomous mode when a warning signal was prompted. This simulator is shown in Figure 1.

Figure 1. Driving Simulator.

The vehicle interior has a gas pedal, brake pedal, shifter knob, turning signal, a dashboard screen, cruise-control buttons, and a steering wheel. A speedometer is presented on the front projection screen for the participant’s use. Five projectors display portions of the driving scenario on a cylindrical projection screen around the vehicle, which provides a 260-degree field of view, with software “knitting” to create a consistent visual field. There is an LCD display integrated for each of the side mirrors and a rear projection screen for the rearview mirror. To capture both the participant’s behavior and the simulated scenario, 4 cameras are mounted in the interior of the vehicle. In addition, two external audio speakers are mounted to the cylindrical screen to provide audio cues about the vehicle’s motion (engine noise, wind noise, passing vehicles, etc.). In relation to the three types of warning signals presented, the vehicle’s audio system was used for presentation of the audio warning signal, while a haptic vibration cushion was placed on the vehicle's seat to present the haptic warning. lights were mounted inside the vehicle on the a-pillar and reflected on the windshield to provide the visual light warning. These warning signal conditions were originally designed for a previous study done in relation to semi-autonomous vehicles, by Trask, Stewart, Kerwin, and Midlam-Mohler (2019). The visual alert was a set of flashing red LEDs fixed to the driver side a-pillar, center console, and windshield. The lights flashed quickly when triggered, with a period of 250 ms and a duty cycle of 60%. The audio warning was a rapid beeping tone from two speakers on either side of the steering wheel. Each produced a tone of 850 Hz that was modulated at a duty cycle of 40% and period of 250 ms. The haptic warning signal used small vibration motors that were embedded with equal spacing of 4cm in the driver's seat cushion. When triggered, the vibration motors pulsed at 80% duty cycle and a period of 250 ms. The motors were wired in three six-by-two arrays in a left, right, and center (Trask et al., 2017).

The simulation was created with SimCreator (RTI) scenario creation software. The scenario imitated a two-lane highway with a relatively normal level of traffic. Autonomous driving was controlled by SimDriver (RTI) software. A warning signal was presented every 45 to 90 seconds, prompting the driver to take control of the vehicle.

Procedure

First, participant consent was obtained, and the participant was given a brief overview of the study. Next, the participant was introduced to the driving simulator and informed of its operation. During the time that the participant was in the simulator, the moderator was in the control room, monitoring the equipment and guiding the participant through the session and as needed through an intercom system. The moderator followed a script which allowed for consistency across participants. A 3-minute practice drive was completed to allow the participant to become comfortable with the differences in feel and responsiveness that come along with the simulator. A 20-minute experimental drive in the scenario came next. Participants were instructed to play Candy Crush on an iPad held in a particular location. Participants were instructed to hold the iPad in their lap and to keep the sound on. At 45- to 90-second intervals, a warning signal (visual, auditory, haptic) was presented. Each warning signal was presented 5 times throughout the experiment in a random order. Re-engagement was measured as time from warning signal onset to the participant putting a hand on the steering wheel or foot on the brake pedal. Participants were also reminded before and during the study that they had the right to stop participation at any point and could withdraw their data.

Chapter 3: Results & Discussion

There were two independent variables in this study. The first independent variable was ASD status (ASD or without ASD), which was a between-subjects variable. The other independent variable was warning signal type (visual, auditory, haptic and none which was a within-subjects variable. The dependent variable was reaction time to re-engage with the vehicle, which was measured by how long it took the participant to come in contact with steering wheel or brake pedal. A two factor, mixed model analysis of variance (ANOVA) was used to analyze the data.

It is important to note that all data analyses should be viewed as preliminary, given the very small number of participants in the ASD group. Appropriate corrections were applied in the ANOVA model to accommodate the differences in sample size, but all analyses should be interpreted with caution. ANOVA results are shown in Table 1.

Independent Variables

Autism Spectrum Disorder Status

Figure 2 shows a graphical representation of the mean reaction time for ASD and without ASD groups for warning type. ANOVA failed to show a main effect of ASD status, although there was a trend towards longer reaction times in the ASD group ($F(1,19)=3.235$, $p=.088$).

Table 1: ANOVA results for ASD status and warning type

	num Df	den Df	MSE	F	ges	Pr(>F)
ASD	1	19	5.199	3.235	0.1033	0.08797
warning	1.696	32.23	1.465	14.01	0.1926	8.969e-05
ASD:warning	1.696	32.23	1.465	0.1625	0.002758	0.8162

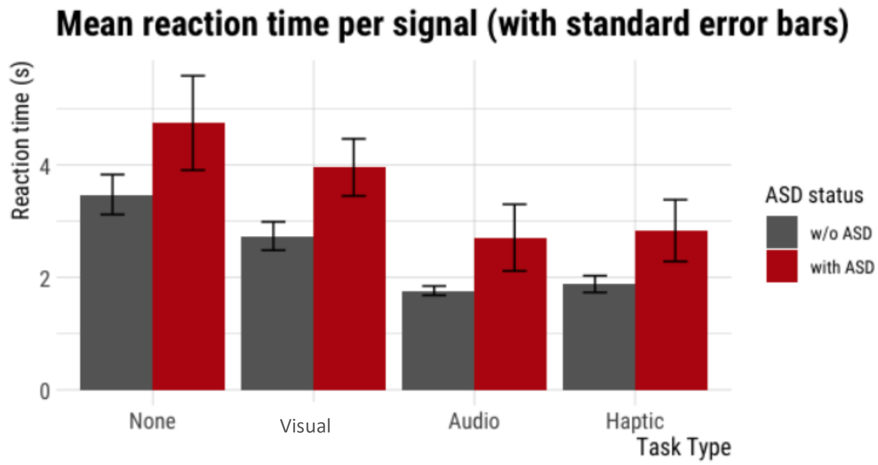

Figure 2: Mean reaction times for individuals with and without ASD for each warning signal type.

Warning Signal Type

Results indicated a significant main effect of warning type ($F(1.696,32.23)=14.01$, $p=.000089$), with haptic and auditory warnings producing the shortest reaction times. Pairwise differences between the different warning types were examined by comparing the estimated marginal means (Table 2). Reaction time for the visual warning was significantly different from auditory and haptic, and no warning was significantly different from the haptic and auditory warnings. No significant difference in reaction time was observed between auditory and haptic warning types.

Table 2: Pairwise differences between the different warning types

level1	level2	estimate	std.error	df	statistic	p.value
X0	X1	0.8913	0.3576	57	2.492	0.07189
X0	X2	1.987	0.3576	57	5.555	4.472e-06
X0	X3	1.931	0.3576	57	5.399	7.941e-06
X1	X2	1.095	0.3576	57	3.063	0.01712
X1	X3	1.04	0.3576	57	2.907	0.02594
X2	X3	-0.05576	0.3576	57	-0.1559	0.9986

X0 = "None", X1 = "Video", X2 = "Audio", X3 = "Haptic"

General Discussion

The present study identified some important trends that merit additional investigation. First, future studies must include a larger and more representative sample of drivers with and without ASD, specifically focusing on larger sample size for the ASD group. Future studies could also include more unpredictable situations, such as rain or fog, or unexpected roadway events such as actions of pedestrians or other vehicles, to make the scenario even more realistic and more representative of real driving situations. Further, the dimensions of the warning signals (e.g., frequency, level, duration) for the present study were chosen on a fairly arbitrary basis. Future studies looking at different stimulus dimensions for their effectiveness in re-engaging drivers would be useful. In addition, including a self-report survey at the end of each test session asking participants directly about the aversiveness of each warning signal would be beneficial to gain more insight into perceptual and emotional dimensions of the warning signals, to suggest possible signal modifications that might be more appropriate.

Chapter 4: Summary and Conclusion

The hypothesis for the present study was that there would be a main effect of ASD status on re-engagement times for taking control of the vehicle, with participants with ASD exhibiting longer reaction times than individuals without ASD. It was also hypothesized that there would be a main effect of sensory modality for the warning stimuli, with the auditory stimuli producing a faster reengagement time than the other modalities. Haptic stimuli were hypothesized to produce an interaction effect, with participants with autism having much longer reaction times than participants without ASD, because of particular sensory defensiveness to tactile stimulations (Pfeiffer and Kinnealey, 2003).

ANOVAs were performed to test these hypotheses. Results indicated a significant main effect of warning type, with haptic and auditory warnings producing the shortest reaction times. Although there was a trend towards longer reaction times for individuals with ASD, analysis failed to show a significant main effect of ASD status. There were no interaction effects, refuting the hypothesis that reaction time for the haptic stimuli would be much longer for individuals with ASD than for individuals without ASD. Reaction time varied, with one ASD participant performing much more quickly than others in the same group. Pairwise differences between the different warning types were examined by comparing the estimated marginal means. Reaction times for the visual warning were significantly longer than for the auditory and haptic warnings, and reaction times for no warning were significantly longer than for the haptic and auditory warnings. There were no significant differences between reaction times for the haptic and auditory warnings. Furthermore, no warning and visual warning conditions produced reaction times that were seconds longer than the auditory and visual warnings, in a situation where seconds may constitute the difference between life and death in the vehicle.

Based on these results, it is evident that warning signal type is important when considering driver re-engagement. Auditory and haptic warnings produced the shortest reactions times and therefore would be the most beneficial to use in a vehicle. However, a haptic warning may be preferred because it is the one sensory modality that is not likely to be otherwise engaged by the occupant of the vehicle. It is anticipated that occupants of autonomous vehicles will be pursuing other activities while the car is driving, including reading, engaging in web surfing or social media, listening to music, viewing videos, or playing games. These activities are likely to involve attentional commitment from the visual and auditory modalities, as well as motor activity from the hands and fingers. Thus, a haptic warning embedded in the vehicle seat may be the most reasonable way to alert a driver of the need to retake control of the vehicle.

There was also no evidence of increased sensory defensiveness in individuals with ASD when presented with the haptic warning. Although there was a trend towards longer reaction time for all of the warning types in individuals with ASD, the lack of a significant difference in reaction time suggests that it may not matter if an individual has ASD or not when considering the optimal kind of warning signal to provide. It is possible that individuals with ASD who also driver's licenses' have, may have less difficultly with sensory integration.

Finally, it is important to re-emphasize that these results are preliminary, and a more extensive analysis should be performed after additional participants with ASD are recruited. It is possible that the data could change substantially with more participants and data collected.

The results of the present study give us new suggested insights in relation to the experience of individuals with autism in autonomous driving. With more investigation, these results can provide automakers with guidelines to accommodate persons with special disabilities, with the goal to make the driving experience inclusive to all users. This will allow individuals with disabilities to have better access to their community, be more independent and have a sense of belonging.

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